PRIMITIVE ONTOLOGY AND LAWS OF NATURE

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Talk Outline

In this talk I would like to present and hopefully discuss a new take on the connection between ontology, laws of nature and properties in physics and metaphysics.
This view has been inspired by the primitive ontology (PO) approach but I do not think is necessitated by it or needs it, so you could endorse it even if you do not endorse the PO approach.
Outline: a summary of the PO approach; a new (maybe crazy) take on how many properties and laws of nature there are.

Primitive Ontology

Basic assumption: scientific realism about fundamental physical theories– physics tells us about reality. But how does it do that?
A physical theory is constituted by a bunch of mathematical variables. But physics is not mathematics: in order for a physical theory to represent the material world we need to give each mathematical object a particular significance. Depending of what significance we give them, we have actually a different picture of reality (under-determination of physics by mathematics).
According to the PO approach there are some mathematical objects that are somewhat privileged: the natural mathematical objects we should take as representing matter are those that live in R^3 or R^4. These objects are the PO of the theory (strictly speaking, the PO is the mathematical object but to simplify things, when it will not cause confusion we will also call PO the material object referring to it).
PO = X in R^3 or R^4 (X here denotes a generic variable, not necessarily the position of something, unless it happens the PO is the one of particles).
Examples:

- <u>Classical Mechanics</u>: the world is made of particles 'living' in a 3-d world, mathematically represented by points in R^3. That is: PO= X (=particle's position) in R^3;
- <u>Quantum Mechanics</u>: the answer depends on which quantum theory we consider.
  - Bohmian Mechanics (BM): the world is made of particles 'living' in a 3-d world, mathematically represented by points in R^3. That is, PO=X (=particle's position) in R^3;

- GRW theory: again, we distinguish between different types of GRW-like theories (see later for what 'GRW-like theory' means):
    - GRWm: PO= X=mass density function m of points in R^3 that has values in R^3: m: $R^3 \rightarrow R^3$
    - GRWf: PO=X (=events) in R^4;
    - GRWp: PO= X (=particle's position) in R^3 ….
- Many-Worlds (MW): again, we distinguish between different types of MW-like theories:
    - Sm: PO= X=mass density function m of points in R^3 that has values in R^3: m: $R^3 \rightarrow R^3$
    - Sf: …
    - …

Law of Motion for the Primitive Ontology

But to specify what exists in the physical world is not all that physics does: it also specifies how it is moves in space through time. This is done by the laws of motion, which specify the (temporal) trajectory of the PO in its natural arena (natural=to be explained later).

Therefore, the other mathematical variables appearing into the theory are necessary to implement the law with which the PO moves.

Trajectory of the PO: Y(t)=f(X,t)

The function f is the one that specifies the law of motion for the PO. It has to be in such a way that the experimental predictions of the theory will match the actual experimental results (that is, such that the theory is experimentally adequate).

Examples:

- <u>Classical Mechanics:</u> PO= X in R^3; f (=law of motion for the PO): deterministic evolution (X double dot=F/m, Newton's 2nd law, where F=force, m=mass)
- <u>Quantum Mechanics:</u> the answer depends on which quantum theory we consider:
    - Bohmian Mechanics:
        - PO=X in R^3;
        - f (evolution of the PO) = deterministic evolution (for particle k with configuration X_k , X_k dot = (hbar/m_k)[Im($\psi*\psi$)/$\psi*\psi$](X_1,…,X_N)) ;
        - g (evolution of ψ)= deterministic (Schrodinger) evolution;
    - GRW theory: again, we distinguish between different types of GRW-like theories:
        - GRWm:
            - PO = mass density function m of points in R^3 that has values in R^3: m: $R^3 \rightarrow R^3$
            - f = indeterministic evolution (complicated to write down);

        - g = stochastic (modified Schrodinger evolution with collapse);
    - GRWf:
        - PO=X (=events) in R^4;
        - f = indeterministic evolution (complicated to write down);
        - g = modified Schrodinger evolution with collapse;
    - GRWp:
        - PO= X (=particle's position) in R^3 ,
        - f = indeterministic evolution (complicated to write down);
        - g = modified Schrodinger evolution with collapse;
- Many-Worlds (MW): again, we distinguish between different types of MW-like theories:
    - Sm: PO= X=mass density function m of points in R^3 that has values in R^3: m: $R^3 \rightarrow R^3$; f = …; g= Schrodinger evolution;
    - Sf:….

…

The Flexible Wave Function and Physical Equivalence

As we just saw, in the case of quantum theories in addition to the PO we have the wave function ψ. In the PO approach, the wave function does not represent matter (because it does not live in R^3 but is a function from R^{3N} to complex numbers, where 3N is the number of degrees of freedom in the theory) but it is involved in the formulation of the law of motion for the PO. Depending on the theory, the wave function evolves according to the function g, which is specified by a particular equation.

Three ingredients: X, the PO, and f, its law of motion in terms of ψ (in quantum theories), which in turns evolve according to the function g. The trajectory of the PO will depend on the evolution of the wave function, that is $Y=f_\psi(X)$ or $Y=f_g(X)$.

We want a theory to be experimentally adequate, i.e., that the experimental predictions match the actual experimental results. This can be accomplished with different POs and different laws of motions as long as Y, the trajectory of the PO, remains the same: the experimental predictions are (macroscopic) results that depend on the (microscopic) trajectories of the PO. Once the trajectories are determined, so are the experimental predictions (different kinds of supervenience?). So, in principle, we could change whatever we want in a theory as long as Y remains the same: we could use a different PO, or f (either modifying the form of f or the wave function evolution g) or both, as long as Y remains the same. This could give rise to unnecessary convoluted and complicated theories, which are in principle possible, though. For instance, one could have a particle PO theory completely empirically equivalent to BM in which the wave function instead of evolving according to the deterministic Schrodinger equation, evolves according to a stochastic evolution (such that Y remains the same – see common structure paper). Or we can have a flash theory completely empirically equivalent to GRWf in which the wave function instead of evolving according to the stochastic GRW equation, evolves according to a deterministic evolution (such that Y remains the same – see common structure paper).

Is stochastic BM the same theory as deterministic BM? Is deterministic GRW the same theory as stochastic GRWf? They differ in the evolution of the wave function but not with respect of the evolution of the trajectories of the PO, so they are physically equivalent. The qualification 'stochastic; and 'deterministic' here refer to the evolution of the wave function, not the PO, and since it is what matters here, they are, for all purposes here, not relevant.

Do we have the same theory if the PO changes? No, because in this way we have changed the metaphysics. Do we have the same theory if f changes but Y remains the same? The theories are physically equivalent and one should probably pick, among the infinitely many possible physically equivalent theories, based on super-empirical criteria like simplicity.

The theories listed above under GRW-type theories have in common only that the evolution of the wave function is stochastic and of the GRW-type. But this evolution is not important under this approach, and can be substituted by other kinds of evolution that preserve the trajectories of the PO remaining with the same theory. So, what do these theories have really in common? [Talk about Equivariance?]

The nomenclature GRWm, GRWf and GRWp as well as the one Sm, Sf, and Sp, relies on the convention that the capital letters in front denote the kind of evolution the wave function has (respectively GRW evolution and Schrodinger one), while the lower case letters at the end identify the PO of the theory (respectively, mass density, flashes and particles). With this notation, one should call BM Sp: particle PO evolving according to a law of motion implemented via a Schrodinger evolving wave function.

This notation, I think, is misleading since it focuses on the evolution of the wave function, which we saw is not fundamental in this approach. What is crucial is the evolution of the PO, which, somewhat ironically, is not even mentioned in here: is the evolution of the PO deterministic or stochastic? What kind of law do we have? One could probably use the following, hopefully a little less confusing, notation:

$\mathrm{PO}_{\text{wf evolution}}^{\text{PO evolution}}$

Main font=PO; subscript= wave function evolution (stochastic or deterministic, and what kind), superscript=PO evolution (stochastic or deterministic, and what kind).

Examples: (in this case X denotes positions of particles')

Old name	New name
BM=Sp	$X_{\text{deterministic}}^{\text{deterministic (Schrodinger)}}$
Sm	$m_{\text{deterministic}}^{\text{deterministic (Schrodinger)}}$
Sf	$(X,t)_{\text{stochastic}}^{\text{deterministic (Schrodinger)}}$
GRWm	$m_{\text{stochastic}}^{\text{stochastic (modified Schrodinger)}}$
GRWf	$(X,t)_{\text{stochastic}}^{\text{stochastic (modified Schrodinger)}}$
GRWp	$X_{\text{stochastic}}^{\text{stochastic (modified Schrodinger)}}$

With this notation, we see that many other theories are possible. […]
Note: all S-PO theories and all GRW-PO theories are empirically equivalent with each other within theory group but they are not outside of it (even if Sm and Sf have a many-worlds character so it is difficult to understand what empirical equivalence amounts to here – see later?): no GRW-kind theory is equivalent to any S-kind theory.

From Micro to Marco

One big motivation for the PO approach: it provides the natural way in which the physical explanation of the behavior of matter goes. That is, in this way the explanation that physics provides of how matter behaves around us is straightforward and does not change much depending of what physical theory we consider.
Macro properties= F(microscopic PO). That is, we have (in principle) complete reductionism with respect of the PO
Other motivation: symmetry: I terms of the PO, it is clear what it means for a theory to have a given symmetry. That is, S is a symmetry of the theory if, when transformed under S, histories of the PO are still histories of the PO.
[One might disagree about the necessity of the PO (see David Albert wave function ontology approach) and approach quantum theories in other ways. In the wave function ontology approach, the world is made of wave function and strictly speaking, there are no particles, no 3-d mass density fields, no spatio-temporal events: everything supervenes on the wave function, in a way that needs specification.]

Fundamental Properties

According to David Lewis (and this seems to be the standard view in this regard), there are the fundamental entities that physics gives us, they have natural fundamental properties, and they evolve according to given laws of nature that are also given to us by physical theories.
In the PO approach, the metaphysics (=what matter is made of) is given by the PO, which evolves in time according to a given temporal evolution.
The PO approach, it seems to me, suggests that we need just the Po and the laws, while the fundamental properties, as they are usually intended may not be necessary.

Let us talk about fundamental properties here. What are they in quantum mechanics? This will be tricky since we have many quantum theories and we all even disagree about which the fundamental ontology should be. So let us start from the 'easy' (less controversial) case of classical mechanics.

<u>Classical Mechanics:</u>

<u>Standard view:</u> Ontology= particles; fundamental properties= position, mass; law of nature: Newton's second law F=ma (forget about charge: that would involves electromagnetic fields and it would be necessary to say whether they belong to the ontology or not and this would complicate the discussion further).

<u>PO approach:</u> just position is a fundamental property, not mass: it appears into the law of motion for the PO just like a parameter.

The situation in QM is more messed up since it is unclear what we are talking about when we talk about QM, but the common view seems to be that mass is still a fundamental property of the ontology (whatever it is). Is that true?

We need to distinguish again which quantum theory we are considering. Let us first see the PO approach and then move on to the wave function approach and let us see what fundamental properties we have on the table.

<u>Quantum Mechanics</u>

<u>Standard view:</u>

- Ontology= (whatever we choose)
- fundamental properties=see above, mass (charge…)
- law of nature: depend on the theory and the choice of the ontology

<u>PO approach:</u> The only fundamental property we have is the one that defines the PO:

- If PO=particles → fundamental property=positions
- If PO= fields → fundamental property=field value (mass field, charge field…)

So, in the PO approach, there are no fundamental properties other than the ones that are necessary to specify the PO (position if a particle PO, mass value if a mass density field PO, and so on).

Laws of Nature

Thought provoking and extreme view that seems to be inspired by the PO approach, but in no major way requires it (that is, also someone that does not buy it can have this view).

Standard view: Ontology, fundamental properties, laws of nature.

Example: CM-Standard view: Ontology= particles; fundamental properties= position, mass; law of nature: Newton's second law F=ma.

Different particles are identified by different masses, and they all follow the same law of motion (Newton's second law).

What if we completely change perspective and say that there is only one kind of entity with no other properties aside what is necessary to mathematically specify it and many laws?
Standard view: Different entities (differentiated by fundamental properties), one law. Protons and electrons are different particles, identified by different masses that follow the same law of nature: F=ma, where for the electron $m=m_e$ and for the proton $m=m_p$. Ex: a proton is a point particle in which the point is, say, green colored; and electron is a point particle in which the point is, say, yellow colored.

In the PO approach, the situation is exactly similar in the case of quantum theories with particles (and easily can be extended in the case of flashes). According to this view, there is only one kind of entity, in this case particles, identified by their positions, and many laws. There are as many laws as there are fundamental particles in the standard view.
Here protons and electrons are different particles not because they have different masses, because there are no masses as fundamental properties; they are different in the sense that they follow different laws of nature. That is, the electron follows law-e: $F=m_e a$, while the proton follows law-p: $F=m_p a$. In this view a proton is a point which has no color which follows the, say, green trajectories; an electron is a point which has no color which follows the, say, yellow trajectories.
The standard explanation in terms of fundamental properties is useful because it makes it easy to classify and identify different particles. For instance, in a theory with a particle ontology we could have electrons and protons which differ in terms of their mass (always forgetting about charge). If there are no fundamental properties other than position of particles, how do we differentiate between different kinds of particles? (In theories with a mass density field we have not this problem: there are two fundamental mass-density fields, one representing the electron and the other the proton. But a similar problem arises with theories of flashes.) If mass is a fundamental property we can say that they have a different mass, but in this case how do we distinguish them? Simple: there is a law for the proton and a law for the electron.

Consequences:
1-There are no fundamental properties, aside from the ones required to specify the PO;
2-There are as many laws as in the standard view there are fundamental entities.

Advantages
<u>1-Spin is not a property</u>: spin as a property is at best a contextual property, namely it depends on the experiment is made (and this is not a very happy state of affair).

If we follow this approach, spin is not a property at all; it is just part of the law of nature that governs the motion of the fundamental object in the theory.

<u>2-Ockham's Razor:</u> People have trouble defining what properties are; here we do not have that problem. Since we have no fundamental properties, we do not have the problem of explaining what properties are! It is a never-ending metaphysical topic to discuss what properties are (….) and no agreement whatsoever about it. In the standard view we have three categories: ontology, fundamental properties of the ontology and laws of nature. Here we have only two: ontology and laws of nature. Since we have fewer categories to account for, Ockham's razor seems to favor the latter approach.

<u>3-Natural:</u> after all, to distinguish a proton from an electron we look at its track in the bubble chamber and we see it curve one way rather than another, we measure its trajectory, not its mass or charge. The only thing one sees is stuff that moves….

<u>4- Massless particles</u>: this view accounts for why the photon has no mass, accounts for the puzzle of the neutrino which does not seem to have any property…

<u>5- Relativity:</u> it seems to be compatible with the fact that in relativity theory the mass changes with velocity. If mass is not a property, then we have no puzzle. One could say that the rest mass is the property, but then she is left to account to explain what the other mass is.

Possible Objections

<u>1-This approach is unnecessarily radical: why do you want to get rid of properties if they function so well in the standard schema?</u>

Reply:

a-It is not unnecessary: the standard approach does not function that well! People have no idea about what properties are […].

b-It is not that radical: in fact, it seems that also the competitive approach in the possible metaphysics of QM, the wave function ontology, suggests the same attitude. If everything is 'made of' wave function, what is its fundamental property? Its field value, which is not the value of the mass of the particles or its positions, as usually intended. […]

<u>2-There are way too many laws! One law for each massive object???</u>

Reply: there is a law for each fundamental particle. The macroscopic objects are made by the microscopic entities in the PO and their behavior can be explained and accounted for in terms of them. Once we discuss the situation at the micro level, there are as many laws as there are fundamental particles. In the standard view we have, say, N

fundamental particles identified by their fundamental properties (masses, for instance) and one law of nature; here we have one kind of particles, and N laws.
The advantage over the standard view is that we do not have to explain what mass is: we have fewer categories, even if more entities per category

3-<u>there are way too many forces</u>: instead of the fundamental 4 forces, we have 4 forces for each particle.
Reply: same as above – we have fewer categories, even if more entities per category.

4-<u>E=mc2: the energy of the particle associated to its mass. How does that fit?</u>
Reply: energy is not a property either
<u>6-what about the Higgs boson? Isn't that supposed to give mass to particles?</u>
Reply: QFT is a mess, detecting particles in high energy physics is extremely complex and indirect…. Who knows what they actually saw….